Int J Life Cycle Assess (2013) 18:796–811
DOI 10.1007/s11367-012-0522-8

LCA FOR FOOD PRODUCTS

Environmental life cycle assessment of a dairy product: the yoghurt

Sara González-García · Érica G. Castanheira · Ana Cláudia Dias · Luis Arroja

Received: 16 April 2012 / Accepted: 15 October 2012 / Published online: 25 October 2012

Abstract
Purpose The dairy sector covers multiple activities related to milk production and treatment for alimentary uses. Different dairy products are available in the markets, with yoghurt being the second most important in terms of production. The goal of this study was to analyse from a cradle-to-grave approach the environmental impacts and energy balance derived from the yoghurt (solid, stirred and drinking yoghurts) manufacture process in a specific dairy factory processing 100 % Portuguese raw milk.
Methods The standard framework of life cycle assessment (LCA) was followed and inventory data were collected on site in the dairy factory and completed using the literature and databases. The following impact categories were evaluated adopting a CML method: abiotic depletion (ADP), acidification (AP), eutrophication (EP), global warming (GWP), ozone layer depletion (ODP), land competition (LC) and photochemical oxidants formation (POFP), with the energy analysis carried out based on the cumulative non-renewable fossil and nuclear energy demand (CED). A mass allocation approach was considered for the partitioning of the environmental burdens between the different products obtained since not only yoghurts are produced but also dairy fodder.
Results and discussion The key processes from an environmental point of view were identified. Some of the potential results obtained were in line with other specific related studies where dairy systems were assessed from an LCA perspective. The production of the milk-based inputs (i.e. raw milk, concentrated and powdered milk) was the main factor responsible of the environmental loads and energy requirements, with remarkable contributions of 91 % of AP, 92 % of EP and 62 % of GWP. Other activities that have important environmental impacts include the production of the energy requirements in the dairy factory, packaging materials production and retailing.

Potential alternatives were proposed in order to reduce the contributions to the environmental profile throughout the life cycle of the yoghurt. These alternatives were based on the minimisation of milk losses, reductions of distances travelled and energy consumption at retailing and household use, as well as changes to the formulation of the animal feed. All of these factors derived from light environmental reductions.
Conclusions The main reductions of the environmental impact derived from yoghurt production can be primarily obtained at dairy farms, although important improvements could also be made at the dairy factory.

Keywords Dairy sector · Environmental analysis · Milk · Portugal

Responsible editor: Ivan Muñoz

S. González-García · A. C. Dias · L. Arroja
CESAM, Department of Environment and Planning,
University of Aveiro,
3810-193 Aveiro, Portugal

S. González-García (✉)
Department of Chemical Engineering, School of Engineering,
University of Santiago de Compostela,
15782 Santiago de Compostela, Spain
e-mail: sara.gez.garcia@gmail.com

É. G. Castanheira
ADAI, Department of Mechanical Engineering,
University of Coimbra,
3030-788 Coimbra, Portugal

1 Introduction

Food is a basic human need. Throughout the years, food production systems have changed from traditional to intensive systems in order to fulfil the demand. Thus, food production systems have become a key factor in the

depletion of resources and climate change (Meissner Schau and Magerholm Fet 2008).

The food industry sector is one of the most important and dynamic manufacturing sectors in Europe with an annual turnover of more than €900 billion being concentred on small- and medium-sized enterprises (European Commission 2011a). The largest sub-sectors are meat, dairy, cereal-based industries and beverages (Wijnands et al. 2007). The dairy sector covers multiple activities related to the production and treatment of milk for alimentary uses. This sector is one of the most important within the European food industry and, due to the growing demand for milk and milk-derived products all over the world, the European Commission proposed an increase in the milk quotas of 2 % from 2008 to 2015 (Eurostat 2006). The dairy sector covers the manufacture of different products which were classified by the NACE Group 15.5 as milk, milk-based products (cream, butter, yoghurts and other milk drinks), cheese, condensed milk and dry products (powdered milk, whey and caseins) (Ramírez et al. 2006).

The main product of the European dairy sector is milk, since this is the raw material for the production of milk-based products. The EU-27 dairy industry produced around 150 million tonnes of raw milk and 10.2 million tonnes of fermented products in 2011. Fermented products include yoghurt, cultured cream and buttermilk (Euromilk 2011).

Yoghurt is a fermented dairy product made by bacterial fermentation of milk. The bacteria used to make the yoghurt are known as *yoghurt cultures*. Fermentation of lactose by these bacteria produces lactic acid, which acts on milk proteins to give yoghurt its characteristic texture and tang.

This study addresses yoghurt production in Portugal. The agro-food sector is the biggest industrial sector in Portugal, and is growing annually. This sector represents a turnover of €13.5 million (in 2009) and contributes to 7.6 % of the gross domestic product (INE 2009). In 2010, around 2.0 million tonnes of milk were produced, with 95 % being cow's milk. Most of the dairy industries are located in the Continental part of the country since this part covers more than 70 % of the Portuguese dairy farms. As in other European countries, milk and other dairy products are important ingredients of the Portuguese diet. In Portugal, the daily dairy products consumption is slightly higher than 350 g person^{-1} day^{-1} (INE 2010).

Regarding the manufacture (and consumption) of Portuguese dairy products, sterilised (ultra-high temperature—UHT) milk in its different forms (whole, semi-skimmed and skimmed milk) is the main product, followed by yoghurts and cheese (INE 2010).

The dairy industry is a good example of an industrial process characterised by the association of different production systems: agriculture, livestock, dairy farming, dairy packaging and distribution (Hospido et al. 2003). According to Korsström and Lampi (2008), the main environmental impacts related to the dairy industry are focused on water consumption, wastewater generation with high organic load and energy requirement. Dairy industries show high water requirements mainly derived from the cleaning of equipment and production facilities as well as for cooling operations. In addition, high thermal energy is required, usually in the form of steam for the heating systems and cleaning. Some of the most energy-intensive processes are the evaporation and drying of milk. Furthermore, there is significant electricity consumption for the operation of machinery, refrigeration, ventilation and lighting. Large amounts of milk are lost during the product manufacturing process (Berlin 2002). Wastewater from this sector contains milk and other product wastes as well as cleaning chemicals. For this reason, the effluents from this industrial sector are characterised as having a high content of organic load, nitrogen and phosphorous (Korsström and Lampi 2008).

Life cycle assessment (LCA) is a standardised methodology for quantifying the environmental profile of products, by evaluating the potential environmental impacts of product systems over their whole life cycle chain (ISO 14040, 2006).

The dairy sector has only been assessed from an environmental point of view, paying special attention to dairy farms (Castanheira et al. 2010; Cederberg and Mattson 2000; Cederberg and Stadig 2003), milk production (Fantin et al. 2012; González-García et al. 2012; Hospido et al. 2003; Høgaas Eide 2002), semi-hard cheese (Berlin 2002) and powdered milk (Ramírez et al. 2006). With regards to yoghurt production—a popular dairy product in the human diet and the second most important dairy product in Portugal, a few environmental studies were found. Glende (1997) assessed the cultured milk production (yoghurts included) using the LCA methodology in three Norwegian factories. Keoleian et al. (2004) presented an environmental study focused on the yogurt delivery system, excluding the yoghurt production in a dairy factory from the assessment. Berlin and Sonesson (2008) assessed the environmental consequences from the manufacture of cultured dairy products (yoghurt, sour cream, cold sauce and crème fraiche with multiple flavours) considering two contrasting models of Swedish dairy factories. As a result, and based on these results, efficient environmental improvements from an LCA approach were proposed for the Swedish post-farm milk chain (dairy industry, retailers and consumers) including not only the production of the yoghurt but also cheese and milk in the analysis (Berlin et al. 2008). According to this study, the potential improvements would not require advanced technical equipment changes or major investments. However, one of the limitations of both studies is that they are focussed on literature studies and assumptions, rather than on real data from dairy factories.

Therefore, this paper can be of interest for the dairy sector since, to the best of our knowledge, it presents a detailed life cycle inventory and the related impacts of yoghurt production from cow's milk for the first time. However, it is important to point out that, although this study was focussed on Portugal, it could be extended to other European countries since the yoghurt production system assessed is representative of the state-of-art technology in use elsewhere (Wijnands et al. 2007).

2 Goal and scope definition

2.1 Objectives

The main objective of this study was to analyse the environmental impacts and energy balance derived from the manufacture of yoghurts derived from cow's milk, which is the second most important dairy product in Portugal as well as in Europe in terms of production (INE 2010). Therefore, the study intended to identify the environmental hot spots of the life cycle under assessment in order to propose improvement options.

To do this, a dairy company located in Portugal, considered state-of-art and using a significant number of technologies and management practices considered as the best available technologies was selected for detailed assessment under a cradle-to-grave approach (Wijnands et al. 2007). Therefore, the entire process was assessed, from the origin of the inputs to the different subsystems involved to the treatment of waste generated during the dairy products manufacture, distribution and consumption. The average daily production of this dairy factory is 1.5 million of units of yoghurt using 100 % Portuguese raw cow's milk as raw material.

In this factory, different yoghurts are produced: drinking yoghurts, stirred yoghurts and solid yoghurts. It was not possible to identify the corresponding mass and energy flows for each yoghurt production line, so the production of all of them as a whole was assessed, considering the system as a black box (Fig. 1).

2.2 Functional unit and allocation method

The selection of the functional unit has an important influence on the results (de Boer 2003) and its choice depends on the aim of study. As mentioned above, the main function of this study is the production of yoghurts from raw cow's milk. The functional unit considered in this study was 1 t of yoghurt at the household.

The dairy factory is a typical multiple-output system and an allocation system was needed in order to assign the environmental burdens to the different co-products. However, not only yoghurts are obtained from the production line. There is also the production of a dairy "residual" stream, which meets quality standards for use as a supplement for animal fodder, specifically as a substitute (after a post-treatment step) for pig fodder (Berlin et al. 2007; Berlin and Sonesson 2008). This dairy stream could replace the portion of soy meal which is by far the leading source of protein used for pig fodder due to its high protein content (Berlin et al. 2007). The production of this high protein content and added value dairy fodder is around 0.08 kg kg^{-1} yoghurt in the dairy factory under assessment. Several authors (Berlin et al. 2007; Berlin and Sonesson 2008) considered a mass-based partitioning between the fodder and the dairy products in order to allocate the environmental burdens. The same perspective was considered in this study between the two different flows: the yoghurts and the fodder. However, the material flows exclusively quantified for the yoghurts, e.g. the packages, were entirely allocated to the yoghurt flow. The remaining flows, such as cleaning agents, electricity or natural gas, were distributed between both co-products following the mass allocation.

The product perspective, which avoids the cultivation and extraction of the equivalent soy meal ration to the pig farmers (Basset-Mens and van der Werf 2005; Eriksson et al. 2005), was not initially taken into account due to the lack of information concerning the processing of this dairy fodder into a valuable meal. However, an approximation of this approach will be discussed later. It is important to remark that the post-treatment process has not been included in the assessment.

All of the information concerning the yoghurt production system was supplied as a black box, so it was not possible to specifically identify material and energy flows corresponding to the different yoghurt production lines. Moreover, this study was focused on the yoghurt's life cycle. The partitioning of the environmental loads allocated to the total yoghurt flow between the yoghurts produced (solid, drinking and stirred) by means of an economic allocation approach (Berlin 2002) using the market prices in Portugal for the products under assessment could be an interesting option. However, the results from this study could not be used to identify improvement options on specific production lines due to this limitation. Thus, in this study, only two main products have been considered: the yoghurt and the fodder.

2.3 Description of the system under study

The system process under study was divided into five main subsystems (see Fig. 1): dairy farm, dairy factory, transport to wholesale and retail, household use and final disposal. The production of capital goods (machinery and buildings) was excluded, as in previous studies (Berlin 2002; Berlin et al.

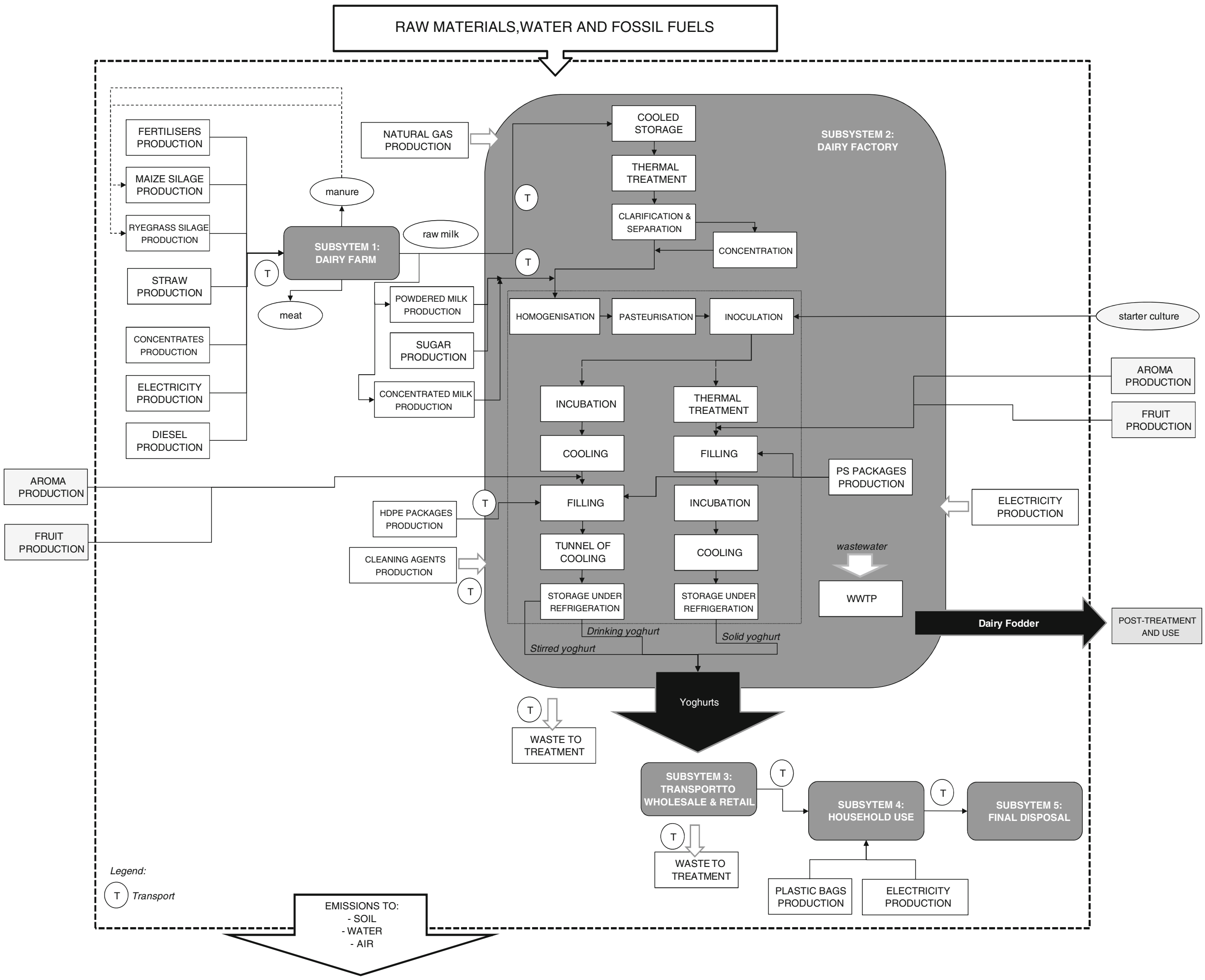

Fig. 1 System boundaries and process chain of the life cycle of yoghurts (solid, drinking and stirred yoghurts) under assessment. *Light grey boxes* were excluded from the system boundaries

2008), as were soil quality changes caused by cultivation-related activities (Høgaas Eide 2002).

2.3.1 Subsystem 1—dairy farm

A typical farm located in Portugal was considered in order to produce the raw milk required in the yoghurt factory. The characteristics of this farm were common to dairy farms that produce most of the milk in the country (Castanheira et al. 2010). This subsystem included agricultural activities related to animal feed (i.e. maize silage, ryegrass silage and straw and concentrates production) and milk production. Detailed information of this farm can be found in Castanheira et al. (2010). As in other studies, cleaning agents required in this subsystem for disinfection were not considered (Cederberg and Mattson 2000) due to the lack of data.

2.3.2 Subsystem 2—dairy factory

This subsystem included all of the activities which took place in the yoghurt factory, from the milk pre-treatment to yoghurt storage and refrigeration. The raw milk received in the dairy factory was stored under cold conditions and underwent a standardisation process to ensure a specific fat content. This stage is known as pre-treatment and was identical for the three yoghurts considered in this study. Firstly, the milk underwent a thermal treatment (pre-pasteurisation) following which the cream was extracted. At this point, the milk presented the required and desired fat content. It is possible that part of the skimmed milk undergoes an increase of its dry extract by means of the evaporation of the water after the cream extraction (concentration process). With this process, the aim is to increase the yoghurt consistency and to reduce the possibility of whey production. In

this step, the treated milk was mixed with powdered and concentrated milk together with sugar and cream in order to obtain the different types of yoghurt according to the fat content (whole, semi-skimmed or skimmed yoghurt) and, this flow was then sent for the homogenisation process which helped to prevent the cream (fat) rising to the surface during fermentation, followed by the pasteurisation process. The pasteurisation was carried out at 90–95 °C, which presented several benefits: (a) it destroyed all of the micro-organisms in the milk which could interfere with the controlled fermentation process; (b) it denatured the whey proteins in the milk to give the final yogurt better body and texture; (c) it did not alter the flavour of the milk and finally, (d) it helped to release the compounds in the milk that stimulated the growth of the starter culture. After homogenisation and pasteurisation, the milk-based flow was cooled at 40–45 °C and the bacterial culture, specific to the particular product, was added to the milk. From this moment, the operations differed with regard to the dairy product under manufacture:

Stirred yoghurts: the incubation was performed in isothermal tanks with pH meters. The incubation time was 2.3–3 h at 42–43 °C. When the pH value was optimal, the mixture was cooled at 15–22 °C in order to stop the culture growth and the increase in acidity. Prior to the filling process, additives such as aroma and fruit (if required) were added to the mixture. Finally, the mixture was placed in polystyrene (PS) packages with 120 g of yoghurt per package. This was usually performed under aseptic conditions, in order to avoid recontamination.

Solid yoghurts: the milk-based flow was heated and the additives were continuously added to it. After that, filling took place in PS packages with 120 g of yoghurt per package. Next, the packages were incubated at around 43 °C for 3–3.5 h. When the pH value was optimal, the packages were continuously cooled to <5 °C.

Drinking yoghurts: there were some differences in the production process for this kind of yoghurt in comparison with the previous ones. After the mixing and cooling processes, the yoghurt was sent to a mixture tank where the additives were added. Next, the yoghurt underwent different thermal treatments depending on the expiration date. The packages used for this yoghurt were made of high-density polyethylene (HDPE) and the storage capacity was 180 g of product.

The starter culture required to make the yoghurts was produced at the dairy factory although it was excluded from the assessment due to the lack of data. Moreover, all of the wastewater from the yoghurt factory, which had a high organic load, was treated in the wastewater treatment plant (WWTP) before the effluents were sent to the river. Solid and stirred yoghurts were stored in PS containers which were also produced on-site. Drinking yoghurts were kept in HDPE containers which were delivered from a nearby factory. All of the containers were sealed with tapes made of polyethylene and packaged in cardboard boxes with plastic film. In the yoghurt production line, there was a consumption of aromas and fruits according to the specifications of the final products. In this study and due to the lack of data, both inputs were excluded from the assessment. The dairy fodder post-treatment and use was not included within this subsystem's boundaries since it was sent to nearby farmers and the factory did not have any information concerning it. Waste generated in the production process, which was mainly derived from the packaging step, was sent for treatment, which was considered in this environmental assessment. According to the Portuguese Environmental Agency (2010), the waste was sent to a sanitary landfill, for energetic valorisation, recycling and/or composting.

Concerning the wastewater generated throughout the production line, this dairy factory has a WWTP within the factory and the corresponding management has been taken into account in this subsystem.

2.3.3 Subsystem 3—transport to wholesale and retail

This subsystem included the distribution of final products from the dairy factory to the market as well as the refrigeration of dairy products during storage. Thus, the electricity requirement in the refrigeration of the yoghurts and diesel consumption in the trucks for the distribution have been quantified. Energy consumption for illumination and air conditioning systems in the wholesaler and retailer were not included within this subsystem boundary due to the small percentage that yoghurts represent among all of the products displayed in stores (Hospido et al. 2006). Moreover, a fraction of dairy products are wasted when they are stored since they are not sold or they are not delivered in time. These losses constitute a small part of the total yoghurt storage and were not considered in the assessment due to the lack of real data. On the contrary, cardboard generated as waste in this stage has been quantified in this study.

2.3.4 Subsystem 4—household use

The consumption stage included the transportation of the yoghurts from the retailer to the consumer, as well as the activities carried out by the consumer after purchasing the yoghurts, namely the refrigeration of the dairy products (Nielsen et al. 2003) and the washing of the spoons used by the consumers (Keoleian et al. 2004). It is known that the consumers generate food wastage which could be taken into account. According to Berlin et al. (2008), the yoghurts were not always consumed within the recommended period, which generated losses. These authors proposed an estimation of wastage of yoghurts at the household of 10 % based

on surveys carried out for 16 Swedish households. These losses are mainly due to the packaging design. The losses of yoghurt at the household were considered together with the packages waste to final treatment.

2.3.5 Subsystem 5—final disposal

This subsystem included the end-of-life processes related to the waste management of yoghurt containers as well as their transport up to the waste management destination.

3 Life cycle inventory, data quality and assumptions

The quality of an LCA study depends on the sources managed for the inventory data collection. In this study, all of the information regarding the foreground data for the production of the raw milk in a typical Portuguese dairy farm (subsystem 1) was obtained from Castanheira et al. (2010), and consisted of real data. The production of the different inputs to (feed production) and outputs from (products, co-products and diffuse emissions) the subsystem were taken into account and were completed with data from the literature when necessary (Gallego et al. 2011).

The foreground life cycle inventory data for the dairy factory (subsystem 2) consisted of average annual data (year 2007) obtained by on-site measurements in the factory. Table 1 shows the detailed global inventory data collected for this subsystem.

It is important to point out that the different transport activities required for the supply of the inputs to the production line as well as the transport activities associated with product distribution and waste transport have been taken into account. Table 2 shows a short description of the different transport modes, the average transport distance and the data sources considered.

When it was not possible to obtain actual data, inventory data were collected from the literature and databases as described below. Moreover, whenever possible, the same databases were used in order to achieve consistency in the results. Information concerning background processes (such as cleaning agents, electricity, packaging materials, concentrated milk, sugar and powdered milk production) were obtained from databases and bibliographic sources. The main input in the dairy factory is the raw milk but the addition of other milk-based products is required, which include powdered milk and concentrated milk. Both products can be considered as co-products of a dairy farm since they consist of milk with a low content of water. Inventory data for the manufacture of both dairy products was taken from Nielsen et al. (2003), but the milk input was adapted to the Portuguese scenario (Castanheira et al. 2010). Depending on the final products, aromas and fruits are required in the production line. However, in this study and due to the lack of data, both inputs were excluded from the assessment.

Table 3 shows a detailed description of the data sources considered. As mentioned before, the production of the starter culture was on-site, but it was not possible to identify the allocated inventory data. Therefore, the environmental burdens derived from this process (i.e. electricity requirements) were included in the total figures for the dairy factory. The Portuguese electricity production profile was adapted to the production model provided by the International Energy Agency (IEA 2009). The energy sources used for the Portuguese electricity mixture were fossil fuels (54 %) such as hard coal, oil and natural gas, hydropower (12.9 %), photovoltaic (0.1 %) and wind power (10.2 %), as well as cogenerated (3.8 %) and imported energy from the Spanish grid (19.0 %).

Different waste was generated at the dairy factory, which was mainly derived from the packaging step, as well as at the wholesaler and retailer (cardboard and plastics). As mentioned before, the waste management was included in the system boundaries as well as the distribution up to the management scenario. For the plastic waste, average ratios were considered for the waste management systems supplied by Plastic Europe (2012) and the Portuguese Environmental Agency (2010). Therefore, it was considered that 25 % of the plastic waste was sent for recycling, 15 % for energetic valorisation, 54 % to sanitary landfills and 6 % for composting. In the case of the paper and cardboard waste, the disposal ratios were taken from the Portuguese Paper Industry Association (Celpa 2011) and the Portuguese Environmental Agency (2010): 50 % was sent for recycling, 36 % to the sanitary landfill, 10 % to energetic valorisation and 4 % to composting. For all types of waste, an average transport distance of 100 km was assumed. Data for the waste treatment systems were taken from Ecoinvent (Doka 2007) (see Table 3).

Concerning the transport to wholesale and retail stages (subsystem 3), the transportation of the different yoghurts were considered to constitute an average distance of 183 km by road (28-tonne truck)—using data supplied by the company. An average annual energy requirement has been considered when storing the yoghurts under cold conditions of 496 $kWh\,m^{-2}$, assuming that the yoghurt remained with the retailer for 3 days and required an area of 0.0064 m^2 (Berlin et al. 2008).

As mentioned before, the household use (subsystem 4) included the purchase of the yoghurt and consumption. According to Hospido et al. (2006) in their study concerning the canned tune, we have considered the same market trend assuming that 30 % of yoghurts are bought at superstores (10 km covered by car), 54 % at stores (foot route) and 16 % at grocery (foot route). This assumption was based on that not only yoghurts are bought but also other foods. Plastic

Table 1 Global inventory for the dairy factory (subsystem 2) per 1 t of yoghurt at the household

Input from technosphere			
Materials		Energy	
Raw milk (from dairy farm)	914.8 kg	Electricity (dairy factory)	134.7 kWh
Powdered milk	41.9 kg		
Concentrated milk	66.4 kg		
Additives		Transport	
Sugar	46.4 kg	Truck 16–32 t (dairy factory—input)	48.6 tkm
Aroma	601.4 g	Truck >32 t (dairy factory—input)	713.2 tkm
Fruits	72.6 kg	Truck 3.5–16 t (dairy factory—waste)	1,118 kgkm
Cleaning agents			
Nitric acid	4.9 kg		
Hydrogen peroxide	18.6 g		
Sodium hydroxide	7.8 kg		
Packaging materials			
Polystyrene	18.8 kg		
HDPE (containers)	25.2 kg		
Cardboard	37.0 kg		
HDPE (film)	2.9 kg		
PET (tapes)	1.5 kg		
Fossil fuels			
Natural gas	16.4 m^3		
Input from environment			
Water	3.2 m^3		
Output to technosphere			
Products		Waste to treatment	
Yoghurts	1.0 t	Paper to recycling	2.4×10^{-2} kg
Solid yoghurts	209.7 kg	Cardboard to recycling	1.0 kg
Drinking yoghurts	432.2 kg	Plastics to recycling	1.1 kg
Stirred yoghurts	358.1 kg	Paper to incineration	4.8×10^{-3} kg
Dairy fodder	78.9 kg	Cardboard to incineration	0.2 kg
		Plastics to incineration	0.6 kg
		Waste to composting	0.4 kg
		Paper to sanitary landfill	1.7×10^{-2} kg
		Cardboard to sanitary landfill	0.7 kg
		Plastics to sanitary landfill	2.3 kg
		Sludge to landfill	4.6 kg
Output to environment			
Air emissions		Water emissions	
Carbon dioxide	110.6 kg	Chemical oxygen demand	1.9 kg
Carbon monoxide	186.3 g	Suspended solids	0.6 kg
Nitrogen oxides	71.9 g	Nitrogen total	6.1×10^{-2} kg
Dinitrogen monoxide	1.1 mg	Phosphorous total	1.4×10^{-2} kg
Methane	10.8 mg		
Organic substances	1.7 g		

bags are required to load the yoghurts at the supermarket and information about the amount of plastic bag required per shop was taken from Hospido et al. (2006). Inventory data for its production was taken from the literature (Hischier 2007). The energy used to refrigerate the yoghurts at home was taken from Nielsen et al. (2003), assuming that a portion of the energy consumed by the refrigerator was allocated to the yogurts, based on the ratio of the occupied yoghurt volume in the refrigerator. Waste generated at the household included the plastic

Table 2 Average distances, transport mode and assumptions considered

Material	Transport mode	km	
Raw milk	Truck >32 t	529	Weighted average data
Powdered milk	Truck >32 t	2,254	Weighted average data
Concentrated milk	Truck >32 t	1,600	Weighted average data
Sugar	Truck >32 t	450	Weighted average data
Cleaning agents	Truck >32 t	250	Weighted average data
Packaging materials	Truck 16–32 t	600	Weighted average data
Yoghurts to wholesale and retail	Truck 16–32 t	183	Weighted average data
Shopping	Passenger car	–[a]	Hospido et al. (2006)
Waste from dairy factory	Truck 3.5–16 t	100	Assumption
Waste from wholesale and retail	Truck 3.5–16 t	100	Assumption
Waste from household use	Truck 3.5–16 t	100	Assumption

[a]The shopping is: 30 % by car (10 km) and 70 % by foot

bags, containers and tapes but not household wastewater (after consumption) due to the lack of information. The same perspective was assumed by Berlin (2002). The management and distribution of this waste was included in subsystem 5 and the average ratios for the plastic waste described before were assumed. An average transport distance of 100 km was assumed. A short description of the global inventory data managed in subsystems 3 and 4 is shown in Table 4.

4 Results and discussion

Among the steps defined within the life cycle impact assessment stage of the standardised LCA methodology, only classification and characterisation stages were undertaken in this study (ISO 14040, 2006). Normalisation and weighting were not conducted, as these optional elements were not considered to provide additional robust information for the objectives established in this study.

Table 3 Summary of data sources considered in this study

Energy	Electricity (Portuguese and Spanish electricity profile)	Ecoinvent database (Dones et al. 2007) and International Energy Agency (IEA 2009)
	Natural gas	Ecoinvent database (Dones et al. 2007)
Milk products	Raw milk	Castanheira et al. (2010)
	Powdered milk	Nielsen et al. (2003) and Castanheira et al. (2010)
	Concentrated milk	Nielsen et al. (2003), Ramirez et al. (2006) and Castanheira et al. (2010)
Cleaning agents	Nitric acid	Ecoinvent database (Althaus et al. 2007)
	Hydrogen peroxide	Ecoinvent database (Althaus et al. 2007)
	Sodium hydroxide	Ecoinvent database (Althaus et al. 2007)
Additives	Sugar	Nielsen et al. (2003)
Packaging materials	Polystyrene	Ecoinvent database (Hischier 2007)
	HDPE	Ecoinvent database (Hischier 2007)
	Cardboard	Ecoinvent database (Hischier 2007)
	PET (tapes)	Ecoinvent database (Hischier 2007)
	Plastic bags	Ecoinvent database (Hischier 2007)
Others	Tap water	Ecoinvent database (Althaus et al. 2007)
Transport	Trucks 3.5–16 t	Ecoinvent database (Spielmann et al. 2007)
	Truck 16–32 t	Ecoinvent database (Spielmann et al. 2007)
	Truck >32 t	Ecoinvent database (Spielmann et al. 2007)
	Passenger car	Ecoinvent database (Spielmann et al. 2007)
Waste treatment	Incineration (plastics, cardboard and paper)	Ecoinvent database (Doka 2007)
	Recycling (plastics, cardboard and paper)	Ecoinvent database (Doka 2007)
	Composting (plastics, cardboard and paper)	Ecoinvent database (Doka 2007)
	Sanitary landfill (plastics, cardboard and paper)	Ecoinvent database (Doka 2007)

Table 4 Inventory data for the for the subsystem 3 (wholesale and retail) and subsystem 4 (household use) per functional unit

Inputs from technosphere	
Materials	
Tap water (household use)	804.5 kg
Plastic bags (household use)	4.0 kg
Energy	
Electricity (wholesale and retail)	186.1 kWh
Electricity (household use)	54.7 kWh
Transport	
Truck 16–32 t (to wholesale and retail)	183.3 tkm
Truck 3.5–16 t (wholesale and retail—waste)	3.5 tkm
Passenger car (to household use)	2,521 persons km
Truck 3.5–16 t (household use—waste)	4.9 tkm
Outputs to technosphere	
Waste to treatment	
From wholesale and retail	
Cardboard to recycling	15.6 kg
Cardboard to incineration	3.1 kg
Cardboard to sanitary landfill	11.1 kg
Cardboard to composting	1.4 kg
From household use	
Plastics to recycling	12.4 kg
Plastics to incineration	7.4 kg
Plastics to sanitary landfill	26.5 kg
Plastics to composting	3.1 kg

The characterisation factors reported by the Centre of Environmental Science at Leiden University (CML 2001 method) were used (Guinée et al. 2001). The following impact potentials were evaluated according to the CML method: abiotic depletion (ADP), acidification (AP), eutrophication (EP), global warming (GWP), ozone layer depletion (ODP), land competition (LC) and photochemical oxidant formation (POFP). Furthermore, an energy analysis was carried out based on the cumulative non-renewable fossil and nuclear energy demand (CED) computed according to Hischier et al. (2007) as an additional indicator. The software SimaPro 7.3.2 was used for the computational implementation of the inventories (Goedkoop et al. 2008).

On the basis of the functional unit defined (1 t of consumed yoghurt in the household), Table 5 displays the environmental results per impact category as well as for the energy analysis.

Figure 2 shows the relative contribution of each subsystem involved for each impact category: dairy farm, dairy factory, transport to wholesale and retail, household use and final disposal.

The impact category results allowed the identification of subsystems with the highest environmental loads. According to the results, the production of raw milk (the main raw material) in the dairy farm (subsystem 1) considerably contributed to the environmental impact in numerous categories (see Fig. 2), such as AP (54 %), EP (55 %), LC (56 %) and POFP (40 %). This is because the activities carried out on the dairy farm considerably contributed to the emission of NH_3, NO_3^- and CH_4 derived from the manure production and management and enteric fermentation, as well as NO_x and SO_2 emissions from diesel combustion in the agricultural machinery. In terms of GWP, this subsystem contributed to 37 % of total contributions (see Fig. 2) mainly as a result of the enteric CH_4 emissions (29 % of total).

Table 5 Impact assessment results (characterisation step) associated with the cradle-to-grave life cycle of 1 t of yoghurt at the household

Impact category	Unit	Total
ADP	$kg Sb_{eq}$	7.86
AP	$kg SO_{2eq}$	29.48
EP	$kg PO_4^{-3}{}_{eq}$	10.06
GWP	$kg CO_{2eq}$	1,776
LC	m^2a	352
ODP	$kg CFC\text{-}11_{eq}$	1.33×10^{-4}
POFP	$kg C_2H_{4eq}$	0.42
CED	MJ_{eq}	17,180

Numerous authors have identified the dairy farm as the dominant contributor to the environmental impacts regardless of the dairy product under assessment (Bartl et al. 2011; Berlin 2002; Berlin et al. 2008; González-García et al. 2012; Hospido et al. 2003; Høgaas Eide 2002). In fact, Berlin (2002) identified in the LCA of a semi-hard cheese (cradle-to-grave perspective) that the farming subsystem contributed to 94 % of the GWP and 99 % of the AP. It is important to point out that subsystem 1 only involved the production of the raw milk, which represented 89 % of the total milk-based inputs in the dairy factory. However, there was also consumption of powdered milk and concentrated milk, whose environmental contribution is included in subsystem 2 and will be assessed later.

Activities specifically related to the yoghurt production, such as the dairy factory (subsystem 2), are the most important factors with significant contributions in all of the categories under assessment: ADP (65 %), AP (42 %), EP (41 %), GWP (53 %), ODP (65 %), LC (43 %), POFP (49 %) and CED (67 %). Therefore, and according to Fig. 2, the environmental impact is basically concentrated in subsystems 1 and 2. Figure 3 displays the relative contributions to each environmental category from the processes or activities involved within the limits of the dairy factory. According to this figure, the production of other milk-based inputs, i.e. powdered milk and concentrated milk, are the main environmental hot-spots with remarkable contributions of 86 % on AP, 89 % on EP, 50 % on GWP, 84 % on LC and 58 % on POFP. Thus, the environmental

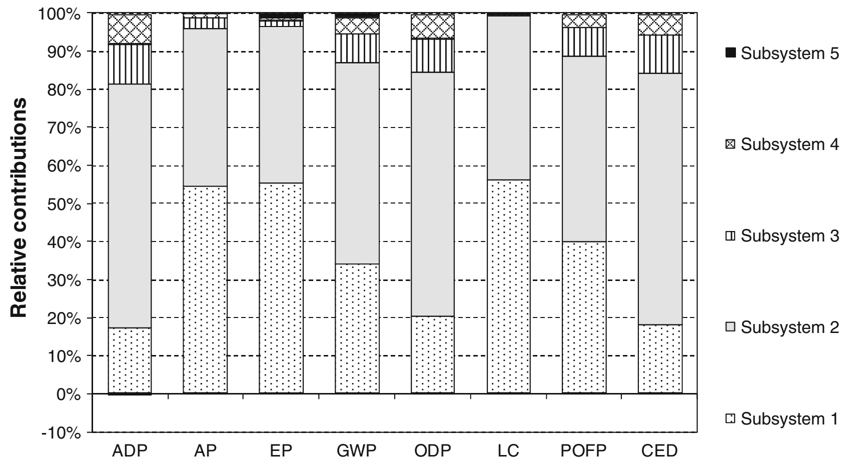

Fig. 2 Relative contributions per subsystems (in percent) to each impact category. Impact category acronyms: *ADP* abiotic depletion, *AP* acidification, *EP* eutrophication, *GWP* global warming, *ODP* ozone layer depletion, *LC* land competition, *POFP* photo-oxidants formation, *CED* cumulative energy demand, *Subsystem 1* dairy farm, *Subsystem 2* dairy factory, *Subsystem 3* transport to wholesale and retail, *Subsystem 4* household use, *Subsystem 5* final use

burdens in this food sector depend considerably on milk-based inputs, so environmental improvement proposals should be focused on them.

The main input in the powdered and concentrated milk production processes is the raw milk derived from the dairy farm. Powdered milk production consists of evaporating milk until it is dry, and concentrated milk is produced by water content removal until it reaches the desired concentration. Both processes are highly energy-intensive processes, and this energy treatment is the unique difference between raw milk and powdered/concentrated milk. It is important to point out that 99 % of the overall contributions to their manufacture are due to the production of the required raw milk, with the remaining 1 % of contributions derived from energy requirements (electricity and heat) and transport activities. This result is expected since around 7.8 and 4 t of raw milk are required per ton of powdered milk or concentrated milk, respectively. In this sense, the improvement proposals for powdered and concentrated milk production should be the same as those proposed for raw milk production.

As shown in Fig. 3, the production of the yoghurt containers and other packaging materials presents remarkable contributions to ADP (41 %) and CED (43 %) due to the PS and HDPE requirements. Both plastic and non-renewable materials require fossil fuels and high energy doses for their manufacture. Other required materials, such as polyethylene tapes, cardboard boxes and plastic film, show a minor influence. Another contributing process to the environmental profile is the production of energy requirements (16 % of ADP and 15 % of CED). All of the electricity requirements are directly taken from the Portuguese grid, which considerably depends on fossil fuels and thermal energy necessity is satisfied by means of natural gas. The proposal of more environmentally friendly fuels or the installation of a cogeneration system could allow the reduction of this environmental load.

In Fig. 3, the role from “others” is also negligible and involves the water requirement, cleaning agent production and treatment of waste generated in the dairy factory, as well as the transport activities related with all of the waste. The

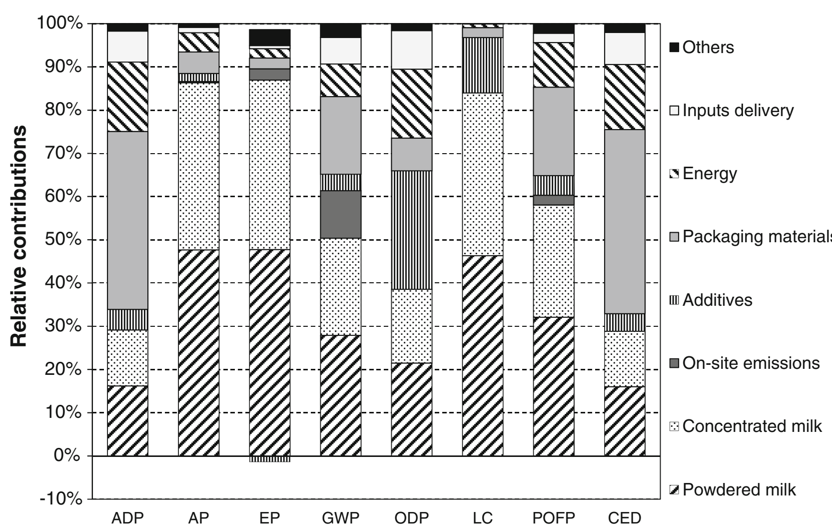

Fig. 3 Relative contributions to each impact category (in percent) per processes involved in the dairy factory (subsystem 2) excluding raw milk production (main input). Impact category acronyms: *ADP* abiotic depletion, *AP* acidification, *EP* eutrophication, *GWP* global warming, *ODP* ozone layer depletion, *LC* land competition, *POFP* photo-oxidants formation, *CED* cumulative energy demand

delivery of inputs to the dairy factory also shows a minor contribution to the environmental profile (less than 10 % in all the categories). However, it is important to mention that powdered and concentrated milk are delivered from long distances (2,254 and 1,600 km, respectively) since they are not produced on the same dairy farm where raw milk is produced. The distribution of raw milk to the dairy factory (529 km) is responsible for the 62 % of contributions from transport activities, and the remaining milk inputs account for 26 %. In Portugal there are few dairy farms and almost all of them are small farms. This leads to long transport times from the dairy farm to the dairy factory as well as to the wholesalers and retailers, which entails high energy requirements. According to Berlin et al. (2008), improvement alternatives on this step by means of the use of new trucks have been proposed which will result in lower tailpipe emissions. In the current study, the use of Euro 5 diesel trucks has been considered, so it is not possible to shift to more environmentally friendly trucks. However, the travelled distance is an important variable. Thus, a sensitivity assessment has been proposed based on the average delivery distance for the milk-based inputs.

Forthcoming activities (the transport of yoghurts from the dairy factory to the wholesale and retail, yoghurt consumption and final disposal)—subsystems 3, 4 and 5—showed a low environmental profile according to Fig. 2. All of them, including the wholesale and retail-related subsystem, presented the highest contributions specifically in terms of ADP and CED (11 and 10 %, respectively). In accordance with Berlin et al. (2008), potential improvements can be achieved in the dairy sector if special attention is paid to the retailer and household-related activities. Therefore, this issue will be discussed in more detail below.

5 Proposal of improvement scenarios

The LCA of yoghurts involved the production of different inputs (milk-based raw materials, additives, water, cleaning agents, containers and energy) and their transportation to the dairy factory, the production of the yoghurts with the corresponding air and water emissions, the treatment and transport of waste generated, the yoghurts retailer, the household and the final disposal of waste.

A general finding which fits with other related studies is that by far the largest contributor to the environmental profile is the milk production. Yoghurts mainly consist of milk (raw milk, concentrated milk and powdered milk) so it is scarcely surprising. The same finding was found by Berlin (2002) for the manufacture of hard cheese.

In order to make substantial improvements in the environmental performance of the yoghurt life cycle, it is necessary to propose improvement activities that allow a reduction of the environmental profile.

5.1 Dairy farm-related scenarios

Castanheira et al. (2010) identified and assessed in detail the environmental performance of raw milk production on a typical Portuguese dairy farm, and the data that discussed here were mainly taken from that study. They identified that activities on the dairy farm (mainly due to enteric fermentation and manure assessment) played the major role in categories such as GWP, AP, EP and POFP. The production of animal feed, specifically the concentrates and maize silage, had the largest contribution to ADP due to the high energy requirements. The same result was found by Hospido et al. (2003) in Galician milk production concerning the concentrates.

It is difficult to propose improvement scenarios for the dairy farm since this is a well-known subsystem (de Boer 2003; Hospido et al. 2003; Berlin et al. 2008; Castanheira et al. 2010) where the dairy factory has limitations for the introduction of changes. Nevertheless, and according to the literature, some changes could be proposed which do not entail costs for the dairy farm but considerably improve the environmental performance. Hoffman (1999) proposed feed grade urea as an additive for the cow's feed due to its content of crude protein and as a supplement for the maize silage which is low in crude protein. However, it cannot be added directly into the feed. Urea can be toxic, so it must be added to the maize silage in a specific way. The urea may be added to maize silage at a rate of 4 kg per tonne of wet silage and the protein content of the silage should be increased from 8 % to 11–12 %. The increment of the protein content should involve a reduction in the maize silage requirements. However, this alternative may not be of interest for dairy farm owners, unless it should reduce costs.

Hospido et al. (2003) proposed changes to the formulation of the animal feed ration, specifically in terms of maize silage doses, without involving changes to the protein and energy supply to the dairy cows. According to that study, part of the grass silage should be changed by an increment of the maize silage requirement which drives the reduction of an environmental impact. According to Iribarren et al. (2011), where the efficiency of 72 different dairy farms was assessed, most of the efficient farms used maize silage and concentrate as the two main feed products, ahead of grass silage and alfalfa. In the current study, the basis of the animal feed was maize silage (1.38 kgkg raw milk^{-1}), grass silage (0.68 kgkg raw milk^{-1}), concentrates (0.31 kgkg raw milk^{-1}) and straw (0.15 kgkg raw milk^{-1}). The maize silage production is one of the main environmental hot spots for the dairy farm (Castanheira et al. 2010) due to the emission of NO_3^- in effluents and NH_3 in the air, with its contribution to the environmental profile being higher than the grass silage contribution regardless the environmental category under assessment. Therefore, the substitution of maize

silage by grass silage was proposed, which presents higher protein content. It was considered that crude protein contents of 8 %[1] and 15 %[2] for maize and grass silages, respectively. A sensitivity assessment was proposed considering reductions of 25 % (scenario A) and 50 % (scenario B) on the crude protein supply from maize silage. These protein reductions should be counteracted with the same amount of protein but from grass silage. Thus, the total protein supply from silages should be maintained. Table 6 shows a short description of the scenarios.

According to the characterisation results (Fig. 4), it should be possible to reduce the environmental for the entire life cycle in all of the categories under assessment, by increasing the consumption of grass silage instead of maize silage. In addition, reductions up to 3 % could be achieved by maintaining the protein supply, especially in terms of ADP, EP, ODP and CED.

The implementation of a treatment system for the manure generated in the farm since it is currently stored in cesspits and after that, it is spread on agricultural lands, could favourably contribute to the reduction of the environmental burdens derived from this subsystem. Treatment systems, such as an anaerobic digestion system with biogas recovery for energy production and digestate valorisation as a fertiliser (Castanheira et al. 2010), could attain environmental reductions with an economic investment.

5.2 Dairy factory-related scenarios

The production of the milk-based inputs is mainly responsible for the environmental profile of the yoghurt life cycle (see Figs. 2 and 3). Part of the processed milk is lost during the yoghurt production process. It is expected that the reduction of wastage of milk should improve the environmental profile for the entire life cycle of the yoghurts.

Berlin (2002) proposed in her study about the cheese, the identification and minimisation of milk losses in the dairy factory without affecting the quality of the final product although it is really difficult to achieve. The minimisation of milk losses should involve the reduction of dairy fodder (Berlin and Sonesson 2008). A sensitivity assessment could be proposed over the volume of the produced dairy fodder with reductions of 10 % (scenario C), 15 % (scenario D) and 20 % (scenario E). These reductions entailed the increment of total yoghurts production around 0.8, 1.2 and 1.6 % respectively, which was also considered in this evaluation.

If more yoghurt is produced, it should involve a higher requirement of inputs in the factory such as packaging materials. However, the material assignment per ton of yoghurt should be approximately the same. In this sensitivity assessment, it has been assumed the same energy requirements (natural gas and electricity) as in the base case. Thus, the energy consumption per functional unit should decrease.

The same allocation approach considered for the base scenario has been taken into account. Thus, the allocation factors for the different co-products (dairy fodder and yoghurt) should change taking into account changes on the corresponding production weights.

According to the comparative results, the minimisation of milk losses could lightly improve the environmental profile in comparison with the current scenario with reductions of up to 1.3 %. Categories related with energy requirements ADP, CED, GWP, POFP and ODP should present the highest reductions being higher for the scenario E.

According to Berlin et al. (2008), the energy efficiency in a dairy factory is closely related to the product that is produced. If the product is UHT milk, the production line requires a lower energy supply than yoghurt production. On the contrary, cheese manufacture should show the highest energy demand. In that study and in accordance with Karlsson et al. (2004), it was established that it should be possible to identify options addressed to increase the energy efficiency up to 8 % in Swedish factories without the necessity for major investments or advanced technical equipment. Therefore, the environmental improvements derived from the reduction of 8 % in the total energy requirements in the dairy factory were assessed. As shown in Figs. 2 and 3, the production of energy requirements in the dairy factory (subsystem 2) is not the main environmental hot spot. Therefore, as expected, the environmental improvements derived from this improvement alternative are almost negligible (less than 1 % in all of the categories), since the effects of energy requirements in the dairy factory on the environmental profile throughout the life cycle are low, and are eclipsed by the milk-based input contributions.

Another interesting variable to take into account is the travelled distance for the supply of the main raw materials: raw milk, concentrated milk and powdered milk. As previously indicated, in Portugal there are few dairy farms and factories, making the supply of milk-based raw materials difficult. A sensitivity assessment could be performed based on the travelled distances, since it could be possible to identify alternative routes for transportation which entail less average distances. The use of a more environmentally friendly transport mode should not be considered in this study, since trucks are the unique possible alternative in Portugal and from the beginning, Euro 5 trucks have been taken into account. Therefore, reductions on the travelled distances for the supply of milk-based inputs of 12.5 and 25 % have been proposed. However, light reductions should

[1] http://www.ag.ndsu.edu/pubs/ansci/dairy/as1253w.htm [accessed March 13, 2012]

[2] http://www.ddc-wales.co.uk/client_files/grass_silage_analysis.pdf [accessed March 13, 2012]

Table 6 Specifications of the assumptions taken into account in the sensitivity assessment of the protein supply from silages used in a dairy farm

Scenarios	Maize silage		Grass silage		Total protein (kg)
	Total (kg)	Protein (kg)	Total (kg)	Protein (kg)	
Base scenario	1,380	38.64	675	32.91	71.55
Scenario A	1,035	28.68	873	42.57	71.55
Scenario B	690	19.32	1,071	52.23	71.55

be achieved all over the life cycle under assessment with this environmental alternative, of not more than 1.5 % in the different impact categories (mainly in ODP and CED).

The production of dairy products and fodder has also been a topic taken into account in several related studies (Berlin et al. 2007; Berlin and Sonesson 2008). In these studies, a mass allocation was considered for the partitioning of the environmental impacts between the co-products. In the current study, that perspective was also considered. However, a comparative sensitivity assessment has been proposed in order to identify the influence on the results when a different perspective is considered. In this sensitivity assessment, it was considered that the total environmental burdens (100 %) should be assigned to the yoghurts and the dairy fodder should be managed as a waste (0 %) since it does not have any economic value for this dairy factory. As expected, a global increment of 8 % on the environmental loads of yoghurts was obtained shifting to this alternative approach.

5.3 Avoided product approach for the animal fodder

The avoided product approach could yield interesting results since the fodder has high protein content and optimum properties to be used as animal fodder, mainly for pigs. As mentioned before, the dairy fodder could substitute the soy meal which has had increasing consumption since the beginning of the 1990s (Eriksson et al. 2005). The dairy fodder could require a post-treatment process but, due to the lack of available information, it was not included in the assessment. Therefore, an environmental comparison was proposed based on this approach. The protein content similar to that of yoghurts has been assumed since this dairy stream is rich in yoghurt waste. Therefore, an average protein content of 4 g per 100 g of fodder was considered. Eriksson et al. (2005) established that 147 g of protein per kilogram of feed is supplied as feed to pigs under a soy meal-based scenario, from which 11.9 % is in the form of soybean.

As shown in Table 1, 78.9 kg of dairy fodder is produced per functional unit, which is required to avoid the production of 7.15 kg of soy meal. Inventory data for the cultivation of the soybean was taken from the LCA food database (Nielsen et al. 2003), but this process involved not only the production of soy meal but also soy oil, both of which are valuable products. According to Eriksson et al. (2005), meal and oil represent 80 and 17 % of the produced mass, respectively. However, there is a large difference on their market price. Therefore, economic allocation (69 and 31 %, respectively) was proposed to partition the environmental burdens between these agricultural products (Eriksson et al. 2005).

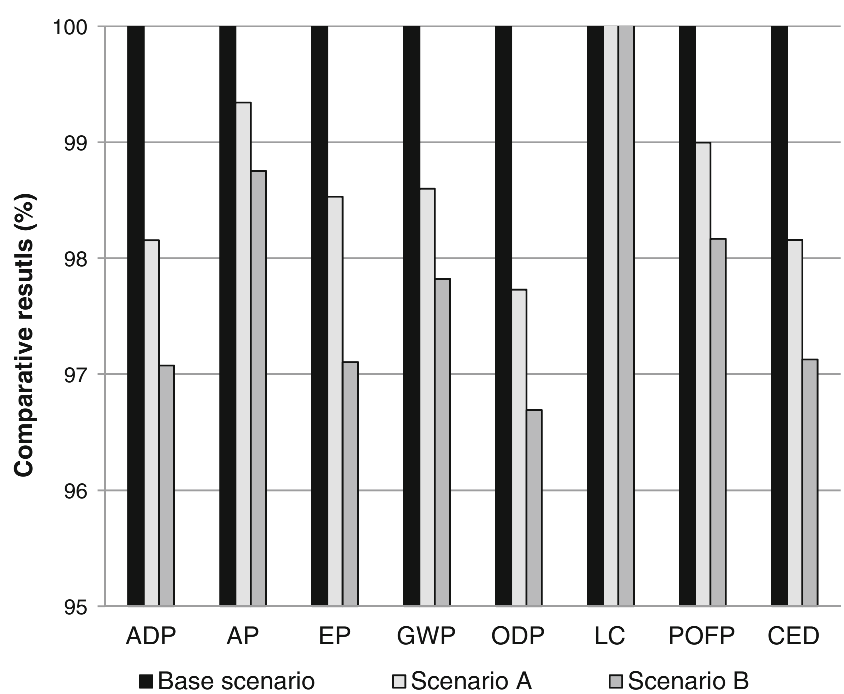

Fig. 4 Comparative environmental results (per functional unit) for the scenarios under study based on changes of the protein supply sources from silages in the dairy farm. *Base scenario* current scenario, *Scenario A* reduction of maize silage dose of 25 %, *Scenario B* reduction of maize silage dose of 50 %

Table 7 Specifications of the assumptions taken into account in the sensitivity assessment of the wholesale and retail, household use and final disposal subsystems

Impact category	Base scenario	Scenario F	Scenario G
Transport			
Wholesale and retail	183 km	160 km	137 km
Waste	100 km	87.5 km	75 km
Energy consumption			
Wholesale and retail	186.1 $kwht^{-1}$	139.6 $kwht^{-1}$	93.1 $kwht^{-1}$
Household—refrigerator	11.3 $kwht^{-1}$	8.5 $kwht^{-1}$	6.6 $kwht^{-1}$
Household—heating water	43.3 $kwht^{-1}$	32.5 $kwht^{-1}$	25.1 $kwht^{-1}$

According to the results, the consideration of the dairy fodder under an avoided product approach does not allow reductions in any environmental category under assessment. Average increments of 8 % should be obtained with this perspective.

5.4 Alternatives for the wholesale, retail and household use and disposal-related subsystems

The contributions to the global environmental profile from the wholesale, retail and household use, as well as the final disposal subsystems are small due to the large contribution from the dairy farm and dairy factory-related activities (see Fig. 2). Therefore, potential improvement alternatives in all of them should not reflect large changes on the results. However, a large amount of attention has been paid to them due to two main parameters: (1) the travelled distances for the supply of the yoghurts to the retailers and waste to treatment and (2) the energy consumption in the retailers and household.

Reductions on the travelled distances from the dairy factory to the retailers were proposed, as were reductions on the waste transportation from household use to the waste treatment installation, of up to 25 %. It is important to point out that the travelled distance considered in the wholesale and retail subsystem (183 km) was supplied by the factory, but the corresponding distance for the waste (100 km) was assumed, so is not real data.

Concerning the energy consumption, Berlin et al. (2008) proposed reductions up to 50 % on the refrigerators and up to 42 % in the household. In the current study, information concerning energy requirements was taken from the literature (Berlin et al. 2008; Keoleian et al. 2004; Nielsen et al. 2003), so the inventory data could not be updated. Table 7 shows the assumptions considered in the sensitivity assessment proposed for these subsystems.

The characterisation results are presented in Fig. 5 and, according to these results, both scenarios derive environmental improvements. Reductions of up to 3 and 6 % all over the life cycle can be achieved respectively for scenarios F and G, respectively, in categories such as ADP, CED and ODP. Important improvements are also achieved in terms of GHG emissions, with reductions of up to 4 % in scenario G.

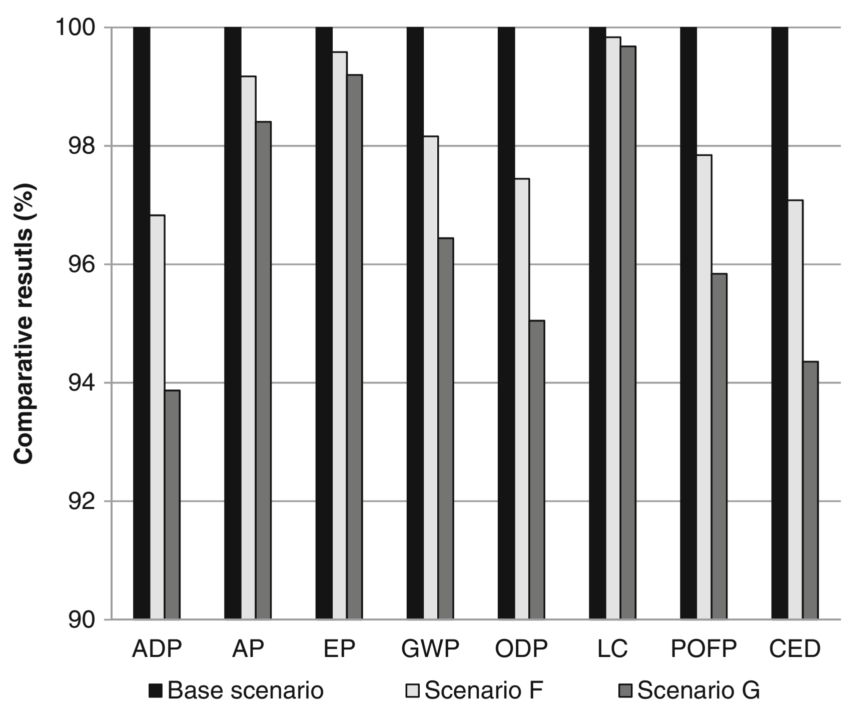

Fig. 5 Comparative environmental results (per functional unit) for the scenarios under study based on changes on the use- and disposal-related subsystems, concerning transport distances and energy consumption

The reductions are mainly derived from the decreases in energy requirements, which is the main hot spot.

6 Conclusions

The dairy sector is one of the most important and dynamic manufacturing sectors in Portugal, covering multiple activities related to milk production and treatment for alimentary uses. The quantification of the environmental burdens derived from yoghurt production (the second most important Portuguese dairy product in terms of production and consumption) was the goal of this study since it is associated with environmental impacts such as acidification, eutrophication and global warming potentials. The study covered the whole life cycle from a cradle-to-grave approach and displayed, for the first time, a detailed life cycle inventory of the corresponding dairy factory.

According to the results, which are in line with other related studies, the environmental impact is basically concentrated on two subsystems: the dairy farm and the dairy factory. The production of the milk-based inputs (i.e. raw milk, concentrated milk and powdered milk) was the main cause of environmental loads and energy requirements with remarkable contributions of 91 % of AP, 92 % of EP and 62 % of GWP. Other activities that have important environmental impacts include the production of energy in the dairy factory, packaging material production and retailing.

Potential alternatives were proposed to reduce the contributions to the environmental profile over the entire life cycle of the yoghurt's production, consumption and final disposal. These alternatives were based on the minimisation of milk losses at the dairy factory, reductions of travelled distances and energy consumption in both retail and household use, as well as changes in the formulation of the animal feed ration. All of these resulted in light environmental reductions. Moreover, the choice of an alternative allocation approach and its influence on the environmental results was also discussed in this study.

Acknowledgements Dr. S. González-García would like to express her gratitude to the Spanish Ministry of Education for financial support (grant reference: EX2009-0740) for a Postdoctoral Research Fellowship taken at University of Aveiro (Portugal), during which this paper was prepared. Dr. A.C. Dias would like to thank FCT (Science and Technology Foundation—Portugal) for the Postdoctoral Fellowship (SFRH/BPD/20363/2004). Érica G. Castanheira would like to thank FCT for the financial support (SFRH/BD/60328/2009), Energy for Sustainability Initiative of the University of Coimbra and MIT PORTUGAL program.

References

Althaus HJ, Chudacoff M, Hischier R, Jungbluth N, Osses M, Primas A (2007). Life cycle inventories of chemicals. Ecoinvent report No. 8, v2.0 EMPA, Swiss Centre for Life Cycle Inventories, Deubendorf, Switzerland

Bartl K, Gómez CA, Nemecek T (2011) Life cycle assessment of milk produced in two smallholder dairy systems in the highlands and the coast of Peru. J Clean Prod 19:1494–1505

Basset-Mens C, van der Werf HMG (2005) Scenario-based environmental assessment of farming systems: the case of pig production in France. Agric Ecosyst Environ 105:127–144

Berlin J (2002) Environmental life cycle assessment (LCA) of Swedish semi-hard cheese. Int Dairy J 12:939–953

Berlin J, Sonesson U (2008) Minimising environmental impact by sequencing cultured dairy products: two case studies. J Clean Prod 16:483–498

Berlin J, Sonesson U, Tillman AM (2007) A life cycle based method to minimise environmental impact of dairy production through product sequencing. J Clean Prod 15:347–356

Berlin J, Sonesson U, Tillman AM (2008) Product chain actors' potential for greening the product life cycle. The case of the Swedish postfarm milk. J Ind Ecol 12(1):95–110

Castanheira EG, Dias AC, Arroja L, Amaro R (2010) The environmental performance of milk production on a typical Portuguese dairy farm. Agric Syst 103:498–507

Cederberg C, Mattsson B (2000) Life cycle assessment of milk production—a comparison of conventional and organic farming. J Clean Prod 8:49–60

Cederberg C, Stadig M (2003) System expansion and allocation in life cycle assessment of milk and beef production. Int J Life Cycle Assess 8(6):350–356

Celpa—Associação da Indústria Papeleira (2011) http://www.celpa.pt/index.php [accessed March, 2012]

de Boer IJM (2003) Environmental impact assessment of conventional and organic milk production. Live Prod Sci 80:69–77

Doka G (2007) Life cycle inventories of waste treatment services. Ecoinvent report No. 13, v2.0 EMPA, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Dones R, Bauer C, Bolliger R, Burger B, Faist Emmenegger M, Frischknecht R, Heck T, Jungbluth N, Röder A, Tuchschmid M (2007) Life cycle inventories of energy systems: results for current systems in Switzerland and other UCTE countries. Ecoinvent report No. 5. Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Eriksson IS, Elmquist H, Stern S, Nybrant T (2005) Environmental systems analysis of pig production. The impact of feed choice. Int J Life Cycle Assess 10(2):143–154

Euromilk (2011) http://www.euromilk.org/upload/docs/EDA/Statistics/EU%20Dairy%20Market%20summaries%202007-2010%20and%202011%20forecast.pdf [accessed March, 2012]

European Commission (2011a) http://ec.europa.eu/enterprise/sectors/food/eu-market/index_en.htm [accessed February, 2012]

Eurostat (2006) http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-BW-09-001/EN/KS-BW-09-001-EN.PDF

Fantin V, Buttol P, Pergreffi R, Masoni P (2012) Life cycle assessment of Italian high quality milk production. A comparison with an EPD study. J Clean Prod 28:150–159

Gallego A, Hospido A, Moreira MT, Feijoo G (2011) Environmental assessment of dehydrated alfalfa production in Spain. Resour Conserv Recy 55:1005–1012

Glende C (1997) Vedlegg til LCA som beslutningsgrunnlag ved fordeling av kulturmelkproduksjon (LCA as a criterion for decisions regarding cultured milk production). M.Sc. thesis, Department of Food Science, Agriculture University of Norway, Ås, Norway

Goedkoop M, de Schryver A, Oele M (2008) Introduction to LCA with SimaPro 7. PRé Consultants, The Netherlands

González-García S, Castanheira EG, Dias AC, Arroja L (2012) Using LCA methodology to assess UHT milk production in a Portuguese

case study. Sci Total Environ. doi: 10.1016/j.scitotenv.2012.10.035

Guinée JB, Gorrée M, Heijungs R, Huppes G, Kleijn R, de Koning A, van Oers L, Wegener A, Suh S, Udo de Haes HA (2001) Life cycle assessment. An operational guide to the ISO standards. Centre of Environmental Science, Leiden

Hischier R (2007) Life cycle inventories of packagings and graphical papers. Ecoinvent report No. 11, v2.0 EMPA, Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Hischier R, Weidema B, Althaus HJ, Bauer C, Doka G, Dones R, et al. (2007) Implementation of life cycle impact assessment methods. Ecoinvent report No. 3, v2.1. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Hoffman P (1999) Adding urea to corn silage. University of Wisconsin Board of Regents. http://www.uwex.edu/ces/crops/uwforage/Adding%20Urea%20to%20Corn%20Silage.htm [accessed March, 2012]

Høgaas Eide M (2002) Life cycle assessment (LCA) of industrial milk production. Int J Life Cycle Assess 7(2):115–126

Hospido A, Moreira MT, Feijoo G (2003) Simplified life cycle assessment of Galician milk production. Int Dairy J 13:783–796

Hospido A, Vazquez ME, Cuevas A, Feijoo G, Moreira MT (2006) Environmental assessment of canned tuna manufacture with a life-cycle perspective. Resour Conserv Recy 47:56–72

IEA –International Energy Agency (2009) Electricity/Heat Data for Portugal Electricity/Heat in Portugal in 2004. http://www.iea.org [accessed March, 2012]

INE—Statistics Portugal (2009) www.ine.pt [accessed January, 2012]

INE—Statistics Portugal (2010) www.ine.pt [accessed February, 2012]

Iribarren D, Hospido A, Moreira MT, Feijoo G (2011) Benchmarking environmental and operational parameters through eco-efficiency criteria for dairy farms. Sci Tot Environ 409:1786–1798

ISO 14040 (2006) Environmental management–life cycle assessment—principles and framework. Second edition. Geneva, Switzerland

Karlsson M, Rohdin P, Karlsson F, Moshfegh B (2004) Energikonsekvenser av strukturerat energieffektivitetstänkande för Arla Foods (EKSET) (Energy consequences found by a structured energy efficient thinking for Arla Foods). Department of Energy Systems, Linköping University of Technology, Linköping

Keoleian GA, Phipps AW, Dritz T, Brachfeld D (2004) Life cycle environmental performance and improvement of a yogurt product delivery system. Packag Technol Sci 17:85–103

Korsström E, Lampi M (2008) Best available techniques (BAT) for the Nordic dairy industry. http://eldri.ust.is/media/skyrslur2002/BAT_mjolkuridn_2001-586.pdf [accessed March 13, 2012]

Meissner Schau E, Magerholm Fet A (2008) LCA studies of food products as background for environmental product declarations. Int J Life Cycle Assess 13(3):255–264

Nielsen PH, Nielsen AM, Weidema BP, Dalgaard R, Halberg N (2003) LCAfood Database. http://www.lcafood.dk [accessed March 13, 2012]

Plastic Europe (2012) http://www.plasticseurope.org/ [accessed March 13, 2012]

Portuguese Environmental Agency (2010) http://www.apambiente.pt [accessed February, 2012]

Ramírez CA, Patel M, Blok K (2006) From fluid milk to milk powder: energy use and energy efficiency in the European dairy industry. Energy 31:1984–2004

Spielmann M, Bauer C, Dones R, Tuchschmid M (2007) Transport services. Ecoinvent report No. 14. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland

Wijnands JHM, van der Meulen BMJ, Poppe KJ (2007) Competitiveness of the European Food Industry. An economic and legal assessment. European Commission. http://ec.europa.eu/enterprise/sectors/food/files/competitiveness_study_en.pdf [accessed March 13, 2012]